

# PROSPECTS FOR DETECTABILITY OF CLASSICAL NOVAE WITH INTEGRAL

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## ABSTRACT

Classical novae are potential gamma-ray emitters, both in lines and in a continuum. Continuum emission (at energies between 20-30 and 511 keV) and line emission at 511 keV are related to positron annihilation and its Comptonization in the expanding shell; <sup>18</sup>F is the main responsible of positron production. The lines at 478 and 1275 keV have their origin on the decay of the radioactive nuclei <sup>7</sup>Be and <sup>22</sup>Na. Updated models of nova explosions have been adopted for the computation of the gamma-ray emission. New yields of some radioactive isotopes directly translate into new detectability distances of classical novae with INTEGRAL.

Key words: gamma rays: observations; novae, cataclysmic variables; nuclear reactions, nucleosynthesis, abundances.

## 1. INTRODUCTION

Novae have been claimed as potential gamma-ray emitters since long ago (Clayton & Hoyle 1974; Clayton 1981; Leising & Clayton, 1987), but they have not been detected yet (Harris, Leising & Share, 1991; Iyudin et al, 1995, 1999; Leising et al. 1988; Harris et al. 1996, 1999; see also Jean et al. these proceedings), probably because the corresponding instruments were not sensitive enough.

A detailed analysis of this emission, based on theoretical models for both the explosion and the production and propagation of gamma-rays, have been presented only recently (Gómez-Gomar et al. 1998; Hernanz et al. 1999a), specially in the context of INTEGRAL and COMPTON satellites capabilities (Hernanz et al, 1997a,b; Hernanz et al. 1999b; Hernanz et al. 2000a). In this paper we update our models, taking into account recent results from nuclear physics which affect nova yields of radioactive isotopes. The detectability distances of novae with the future SPI instrument onboard INTEGRAL are updated accordingly.

## 2. NOVA MODELS

The emission of gamma-rays from classical novae is related to the radioactive decay of some unstable isotopes, synthesized during the explosion. The most relevant ones are: <sup>13</sup>N ( $\tau=862$  s), <sup>18</sup>F ( $\tau=158$  min), <sup>7</sup>Be ( $\tau=77$  d), <sup>22</sup>Na ( $\tau=3.75$  yr), together with <sup>26</sup>Al ( $\tau=1.04 \times 10^6$  yr). The amount of radioactive nuclei in the expanding ejecta determines the number of available photons and positrons, whereas the physical conditions of the ejecta (mainly densities, velocities and chemical composition) determine its opacity to positrons and gamma-rays and, consequently, the final amount of gamma-ray radiation produced which escapes. Therefore, complete models of the explosions, yielding the complete physical conditions of the ejecta (and, in particular, its content of radioactive isotopes) are needed, together with a detailed treatment of gamma-ray production and propagation, in order to compute theoretical models of gamma-ray emission (see Gómez-Gomar et al., 1998, for details).

The nova models have been computed with the hydrodynamic code SHIVA (see José & Hernanz, 1998, for details), which includes a complete reaction network with updated nuclear reaction rates (see José, Coc & Hernanz, 1999 and Hernanz et al. 1999a). Both CO and ONe novae are considered, with initial luminosity  $10^{-2}L_{\odot}$  and accretion rate  $2 \times 10^{-10}M_{\odot}/\text{yr}$ . The main properties of the ejecta relevant for their gamma-ray emission are shown in table 1; the yields of the short-lived isotopes <sup>13</sup>N and <sup>18</sup>F correspond to 1 hour after peak temperature. A quick look at the table shows that <sup>7</sup>Be is mainly produced in CO novae, whereas <sup>22</sup>Na and <sup>26</sup>Al are mainly synthesized in ONe novae. The short lived isotopes <sup>13</sup>N and <sup>18</sup>F are produced by roughly the same amounts in both nova types. These results have important consequences in the ensuing gamma-ray emission, as shown below.

It is important to notice the origin of the main changes between these results and those presented by us some years ago. There have been important changes in the nuclear reactions affecting <sup>18</sup>F syn-

thesis.  $^{18}\text{F}$  synthesis depends mainly on the rate of the  $^{18}\text{F}(\text{p},\alpha)$  reaction. New rates from Utku et al. (1998) lead to reductions of the  $^{18}\text{F}$  yields by factors of around 10 (yields in table 1 as compared with those in Gómez-Gomar et al. 1998). The resulting reduction in the prompt gamma-ray emission (at energies between 20-30 and 511 keV, see below) of both CO and ONe novae is of the same order. Unfortunately, there is still a large uncertainty, by a factor of  $\sim 300$ , affecting those rates (see Coc et al. 2000).

For  $^{22}\text{Na}$  and  $^{26}\text{Al}$ , the changes have been minor, but also deserve some attention, mainly because there is still some uncertainty remaining. The main reaction rates affecting  $^{22}\text{Na}$  synthesis are  $^{21}\text{Na}(\text{p},\gamma)$  and  $^{22}\text{Na}(\text{p},\gamma)$ , leading to uncertainties in the yields of roughly a factor of 3, although very recently the uncertainty of the  $^{21}\text{Na}(\text{p},\gamma)$  reaction has been reduced from 5 orders of magnitude to 1 (Smirnova & Coc, 2000).

### 3. SPECTRA AND LIGHT CURVES

According to its duration and time of appearance, gamma-ray emission produced during nova explosions can be considered as prompt emission and long-lasting emission. The prompt emission is related to positron annihilation, with the positrons coming from  $^{13}\text{N}$  and  $^{18}\text{F}$  decays. Prompt emission consists of a line at 511 keV plus a continuum below this energy, with a cutoff at 20-30 keV, related to photoelectric absorption. This continuum comes from both positronium emission and Comptonization of 511 keV photons (see Gómez-Gomar et al. 1998 and Hernanz et al. 1999a for details). The prompt emission is the most intense gamma-ray emission from novae, but it has very short duration and appears only a few hours after the explosion (defined as time of  $T_{\text{peak}}$ , which occurs before the maximum in visual luminosity). That's because of the short decay times of  $^{13}\text{N}$  and  $^{18}\text{F}$ . This emission is also strongly dependent on the transparency of the model at these very early times.

The long-lasting emission consists of lines at 478 keV ( $^7\text{Be}$  decay) and 1275 keV ( $^{22}\text{Na}$  decay). There should also be a line at 1809 keV, related to  $^{26}\text{Al}$  decay, but the long lifetime of this isotope prevents to observe this line in individual objects, since the time interval between two successive Galactic nova explosions is much shorter. Here we concentrate on the emission by individual novae and, therefore, we don't take into account  $^{26}\text{Al}$  emission.

In figures 1 and 2 we show the gamma-ray spectra of a CO ( $1.15 M_{\odot}$ ) and two ONe novae ( $1.15$  and  $1.25 M_{\odot}$ ) at different epochs after the explosion (all these novae belong to the fast or very fast speed class, whereas the  $0.8 M_{\odot}$  one would be slow or moderately fast). It can be seen that both nova types display a prominent 511 keV line (which disappears very fast, see light curves in figure 3). In addition to this line and to the continuum below it, CO novae show the

478 keV line during some days (see Gómez-Gomar et al. 1998), whereas ONe novae show the 1275 keV line, lasting for some months (see figure 4). The different features of CO and ONe novae in models considered are strictly related to their different nucleosynthesis: CO novae produce larger amounts of  $^7\text{Be}$  than ONe novae, whereas the reverse is true for  $^{22}\text{Na}$ . The effect of the white dwarf mass is shown in figure 2 for the ONe novae. In this case, slight differences appear, since both the content of radioactive elements and the dynamic properties of the ejecta are similar. In the CO case, on the contrary, the two chosen models are quite different in what concerns the dynamics (the  $0.8 M_{\odot}$  nova is quite opaque, as compared to the  $1.15 M_{\odot}$  one; see Gómez-Gomar et al. 1998). Consequently, the fluxes during the prompt emission are smaller. Also, the smaller content of  $^7\text{Be}$  in the low mass CO case leads to a smaller flux of the 478 keV line (see Gómez-Gomar et al. 1998).

### 4. DETECTABILITY WITH INTEGRAL/SPI. DISCUSSION

The  $3\sigma$  detectability distances of our models with the SPI instrument onboard INTEGRAL are shown in table 2. To compute them, we have fully taken into account the line profiles and the total integration time. The 478 keV line is not very broad (FWHM: 3-7 keV), but the 1275 keV line is quite broad (FWHM: 20 keV). This is crucial for the detectability distances, since SPI's sensitivity worsens for broad lines. Concerning the 511 keV line, its FWHM ranges from 3 to 8 keV, but the short duration of the emission prevents to adopt the nominal  $10^6$  s observation time. In this case, 10 hours integration time, starting 5 hours after the explosion, has been adopted.

There is an extra problem with the 511 keV line, related to its early appearance before optical detection. This leads to detection only possible if a nova falls in the FOV of the instrument when it is doing another observation (like the Galactic Plane Survey or the Central Radian Deep Exposure, for instance). We have also considered alternative ways to detect this intense emission, through the SPI's shield (see Jean et al. 1999). It is very important to stress that the successful detection of the annihilation emission from novae strongly relies on the availability of a *posteriori* analyses, like those we are doing with BATSE data (see Hernanz et al. 2000b) or those done by Harris et al. (1999) with the TGRS instrument onboard the WIND satellite.

In table 2 we also show the detectability distances for the continuum, defined to be *optimal* for SPI, i.e., between 170 and 470 keV (with integration time 10h, like for the 511 keV line). It is worth mentioning that the flux emitted in the continuum is larger than the flux in the 511 keV line, but the high spectral resolution of SPI makes its detectability harder and, therefore, detectability distances for the continuum are not larger than those for the 511 keV line. However, this intense continuum flux (still larger if the

full 20-511 keV range is included) poses some hope in its future detectability by large FOV instruments, doing all-sky surveys in hard X-rays up to some hundreds of keV, like the EXIST instrument.

In summary: SPI detectability distances for the 1275 keV line from ONe novae are around 1 kpc, during months after the explosion, and detectability distances for the 478 keV line from CO novae are around 0.5 kpc, during weeks after the explosion. These figures imply that during INTEGRAL's nominal lifetime, 2 years, no more than one or two novae could be detected in the 1275 keV line (for the 478 keV line the situation is worse and for the 511 keV one it will depend on some yet not fixed procedures). However, since the distance of novae is not well determined in many cases (at least before a deep analysis of the optical-UV-IR observations during some months), conservative assumptions concerning optical brightness at discovery-maximum should be adopted, in order not to miss *the good one*.

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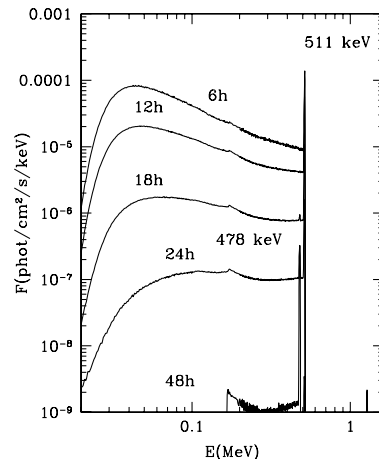


Figure 1. Spectral evolution of a  $1.15 M_{\odot}$  CO nova

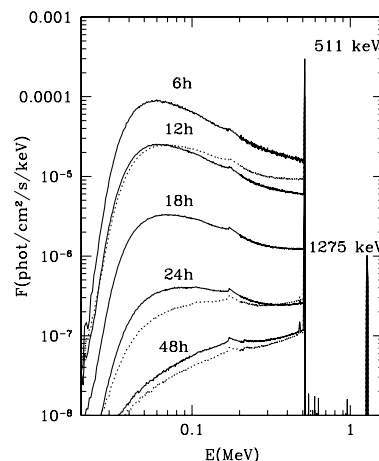


Figure 2. Spectral evolution of  $1.15$  (solid) and  $1.25 M_{\odot}$  (dotted) ONe novae

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Table 1. Radioactivities in novae ejecta

Nova	$M_{\text{wd}}(M_{\odot})$	$M_{\text{ejec}}(M_{\odot})$	KE (erg/g)	$^{13}\text{N} (M_{\odot})$	$^{18}\text{F} (M_{\odot})$	$^7\text{Be} (M_{\odot})$	$^{22}\text{Na} (M_{\odot})$	$^{26}\text{Al} (M_{\odot})$
CO	0.8	$6.2 \times 10^{-5}$	$8 \times 10^{15}$	$1.5 \times 10^{-7}$	$1.8 \times 10^{-9}$	$6.0 \times 10^{-11}$	$7.4 \times 10^{-11}$	$1.7 \times 10^{-10}$
CO	1.15	$1.3 \times 10^{-5}$	$4 \times 10^{16}$	$2.3 \times 10^{-8}$	$2.6 \times 10^{-9}$	$1.1 \times 10^{-10}$	$1.1 \times 10^{-11}$	$6.1 \times 10^{-10}$
ONe	1.15	$2.6 \times 10^{-5}$	$3 \times 10^{16}$	$2.9 \times 10^{-8}$	$5.9 \times 10^{-9}$	$1.6 \times 10^{-11}$	$6.4 \times 10^{-9}$	$2.1 \times 10^{-8}$
ONe	1.25	$1.8 \times 10^{-5}$	$4 \times 10^{16}$	$3.8 \times 10^{-8}$	$4.5 \times 10^{-9}$	$1.2 \times 10^{-11}$	$5.9 \times 10^{-9}$	$1.1 \times 10^{-8}$

Table 2. SPI  $3\sigma$  detectability distances (in kpc) for lines and continuum

Nova type	$M_{\text{wd}}(M_{\odot})$	511 keV line	478 keV line	1275 keV line	continuum (170-470) keV
CO	0.8	0.7	0.4	-	0.4
CO	1.15	2.4	0.5	-	2.0
ONe	1.15	3.7	-	1.1	3.0
ONe	1.25	4.3	-	1.1	3.0

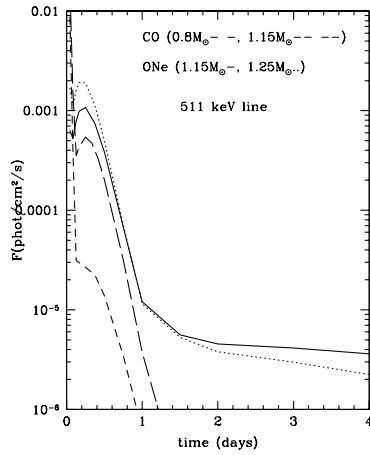


Figure 3. Light curves of the 511 keV line for CO and ONe novae

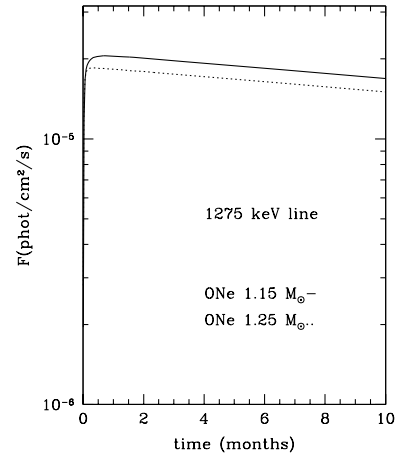


Figure 4. Light curves of the 1275 keV line for ONe novae